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TITLE Preliminary Insulation Estimates for the G. E. Extra-High Voltage Project		

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TITLE
Preliminary Insulation Estimates for the G. E.
Extra-High Voltage Project

ABSTRACT An estimate is made of the minimum insulation requirements for 460 KV and 650 KV transmission systems. These requirements are to be duplicated as far as possible in the GE E.H.V. experimental system. Later data may modify the calculated values to some extent.

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CONCLUSION The conclusions as to insulation strengths are summarized on page 1 of this report.

By cutting out this rectangle and folding on the center line, the above information can be fitted into a standard card file.

For list of contents-drawings, photos, etc. and for distribution see reverse side.

INFORMATION PREPARED FOR Systems Research / P.A. Abetti

TESTS MADE BY High Voltage Laboratory Personnel

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SUMMARY OF INSULATION REQUIREMENTS*

	Voltage Levels		
	115 KV	460 KV	650 KV
TRANSMISSION LINE			
Line BIL (Minimum 1.5 x 40 µs impulse withstand for either polarity of clean insulators under poor atmospheric conditions.)	760 KV	1900 KV	2550 KV
Number of 5-3/4" string insulators	10	25	36
Horizontal strike distance from vertical string to tower steel.	92"	20.1' 242"	29.4' 353"
Minimum Phase-to-Phase Spacings			
H-Frame or Corset-Type Tower	Spacing set by strike distance above.		
Portal Type Tower	Not Used	24.2' 290"	31' 372"
Ground Wires	Two ground wires set for not more than 30° shield angle for widest phase-to-phase spacing to be tested (50 feet) on portal tower.		
Mid-Span Clearance to Ground	25 ft.	41 ft.	49 ft.
SUBSTATION & TERMINAL EQUIPMENT			
Transformer BIL	450 KV	1425 KV	1925 KV
(Use 550 KV BIL on output side of regulating transformer to allow for 30% voltage step-up. Also use 550 KV on low side of 650 KV auto-transformer.)			
Circuit Breaker BIL	450 KV	1425 KV	1925 KV
Station BIL to Ground (Withstand under poor atmospheric conditions)	550 KV	1550 KV	2175 KV
Station Strike Distances			
Air Gap to Ground	41"	131"	182"
Phase-to-Phase**	62"	196"	272"
Air Disconnect Switch Gap Spacing	48"	144"	200"
Lightning Arrester Ratings			
Type (Station)	H	3-K	3-K
RMS Voltage Rating	97 KV	363 KV	513 KV

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* Note that these are probable minimum requirements. In some cases it may be desirable to increase the insulation requirements where economically feasible.

**Station phase-to-phase spacings are based on minimum flashover requirements. The mechanical forces during short-circuit may make wider spacings desirable.

INTRODUCTION

The insulation requirements for the GE Extra-High Voltage Project cannot be assessed accurately until extensive model data on switching surge magnitudes and lightning voltage magnitudes have been obtained. However, since it may be several months before these data are available, estimates of insulation levels must be prepared for preliminary design purposes. These levels are presented in this memorandum.

There are two possible approaches toward setting the insulation levels for the GE Extra-High Voltage Project. One is to set the insulation strengths at values sufficient to withstand the stresses likely to be encountered during the progress of the tests. The other is to not only supply the test system with adequate strength for its own needs but also to increase this strength wherever necessary to duplicate an actual operating system. The latter approach makes greater insulation demands, since it requires insulation strengths of higher magnitudes to withstand long line switching and greater exposure to lightning.

The second approach will be used in this estimate, keeping the objective in mind that the project results will be a prominent factor in the choice of insulation which a utility may adopt for a 460 KV or 650 KV system.

There are at present several characteristics of an extra-high voltage system that must be known for evaluation of insulation requirements. These are:

1. Switching Surges

The magnitudes of switching surges which will be produced on the system must be predicted. These depend on the nature of the system, the quality of its breakers, and the system switching procedures. Until more precise data become available from further research on both full-scale systems and models, a maximum switching surge magnitude of 2.8 X crest line-to-ground voltage will be used for both station and lines. This is consistent with present practices of AG&E for breakers limited to only one restrike. Bellaschi(1) states that switching surges of 2.5 X normal are seldom exceeded, and that at Bonneville 85% of the surges were less than 1.5 X normal. Thus the 2.8 X normal assumption contains a safety factor of about 12% over the 2.5 X normal value. However, it is somewhat low when compared with model test data reported by I. B. Johnson(2) of as high as 3.2 X normal on lines of a 330 KV system. With the advent of reduced system insulation, field data are now badly needed to verify these design values. It is probable that the lightning arresters on the Evaline system will limit switching surge magnitudes to considerably less than 2.8 X normal because of the short length of line used.

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(1) P. L. Bellaschi, "Electrical Clearances for Transmission Design at the Higher Voltages," AIEE Trans., Vol. 73, Part III-B, Oct. 1954, pp. 1192-1200.

(2) I. B. Johnson, "Switching Surges and Arrester Performance on High Voltage Systems," CIGRE, Paper 306, 1958.

2. Magnitude of Lightning Surge Voltages

The magnitude of lightning surge voltage on the line is directly related to the size and geometry of the towers and the nature of the tower footing resistances. Preliminary values are now being obtained from research on tower geometrical models. Since the proposed towers are no higher than the AG&E 345 KV towers and insulated for either 460 KV or 650 KV, it does not appear likely that lightning surge flashover will be a major problem if the line has sufficient switching surge and sixty-cycle strength. However, if a vertical circuit tower construction is adopted, or if an EHV line is run through rocky terrain (high footing resistance), the prevention of lightning outages would be difficult.

3. Lightning Arrester Ratings

The rating of the lightning arrester is determined by the ratios of positive sequence impedances to zero sequence impedances at any faulted point of the line. This determines the increase of potential on unfaulted conductors which the lightning arrester may have to close off against. In these preliminary calculations, a 75% arrester is assumed, based on approximate impedance calculations. These calculations are to be supplemented by a.c. board analysis at a later date.

4. Insulation Breakdown Data

Insulation breakdown data are being obtained on long string insulators, pedestal insulators, and other components. These data are not yet complete, so estimates can be made only on the rough data available.

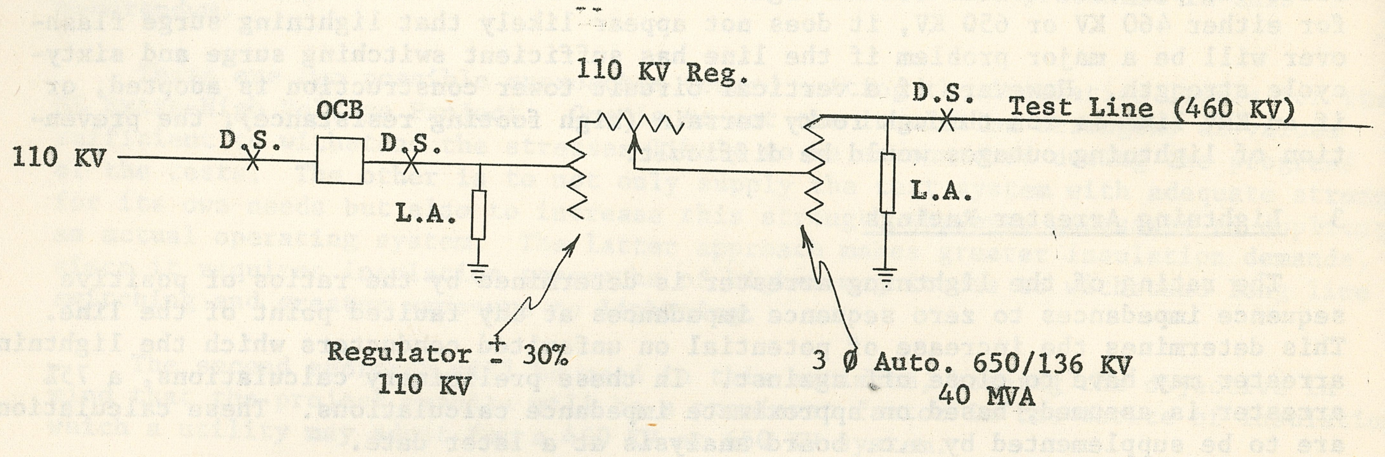
5. System Circuits

Fig. 1 shows the circuits which were studied for these calculations. All lightning arresters for the 460 and 650 KV lines are the GE 3-K Arrester not yet in production. The circulating current circuit for the years 1961-62 is not included, since more accurate data on the voltages to be expected in this system should be available later in the year.

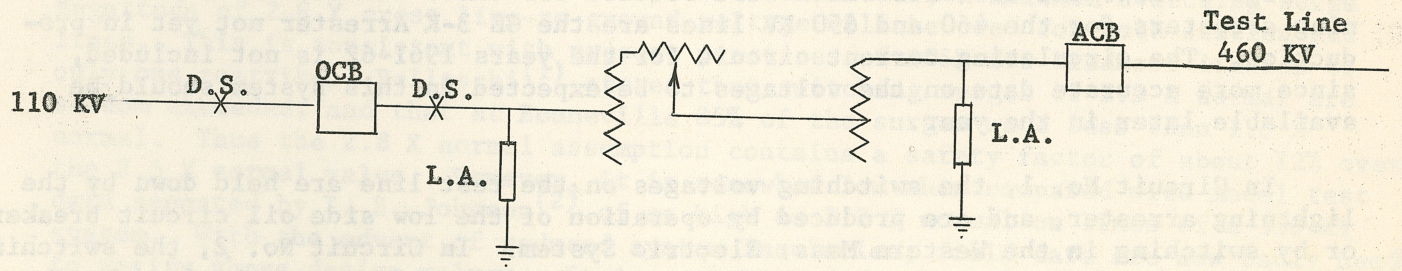
In Circuit No. 1, the switching voltages on the test line are held down by the lightning arrester, and are produced by operation of the low side oil circuit breaker or by switching in the Western Mass. Electric System. In Circuit No. 2, the switching surges may be produced by the 460 KV air circuit breaker and are not limited by the lightning arrester. This is the condition that would occasionally be encountered in an actual 460 KV system. It requires increased line insulation and increased circuit breaker insulation. These increased insulation requirements should be complied with on the experimental line. Similar comments apply to Circuits No. 3 and No. 4 respectively. No attempt is made to analyze the effects of interruption of capacitance charging current with simple disconnect switches. Consultation with Pittsfield people has resulted in the opinion that trying to interrupt the line charging current with disconnect switches at either 460 KV or 650 KV is far beyond our present experience and might result in equipment damage.

FIG. 1

Circuit No. 1



Circuit No. 2



Circuit No. 3

Same as Circuit No. 1, except test line is at 650 KV.

Circuit No. 4

Same as Circuit No. 2, except test line is at 650 KV.

LINE INSULATION

Figure 2 shows the preliminary results of critical wet switching surge and impulse strengths of long insulator strings up to forty-two 5-3/4" units. These tests are still in progress. The number of insulator units required to withstand a 2.8 X normal switching surge is computed in Table 1. Note that these calculations were based on only the 12% safety factor inherent in the assumption of 2.8 X normal switching surge magnitude plus one insulator for breakage. This may appear as a drastic cut in the margin of safety. However, that this will produce a sufficient insulation level can be seen from Fig. 3 which plots the number of equivalent 5-3/4" insulators against system KV for a number of EHV systems. The number of insulators calculated in Table 1 falls within the expected range for 460 KV and 650 KV systems. The difference in safety factors is resolved when it is recalled that although many methods of line calculation use much higher safety factors, they allow only 10% for the difference between impulse and switching surge strength and another 10% for non-standard atmospheric conditions. This is a 20% reduction below the impulse strength, whereas Fig. 2 shows an actual reduction of about 40%.

TOWER CLEARANCES & PHASE-TO-PHASE SPACINGS

In this preliminary estimate, very meager data are available on switching surge flashover to tower. These data consist of just two test points where flashover from a string insulator to an equivalent adjacent tower occurred. Based on these data, Table 3 has been prepared.

The phase-to-phase spacings are based primarily on the minimum strike to the tower steel for a corset-type tower, and on the Thomas formula (AIEE Trans., 1928) for a portal tower with no steel between phases.

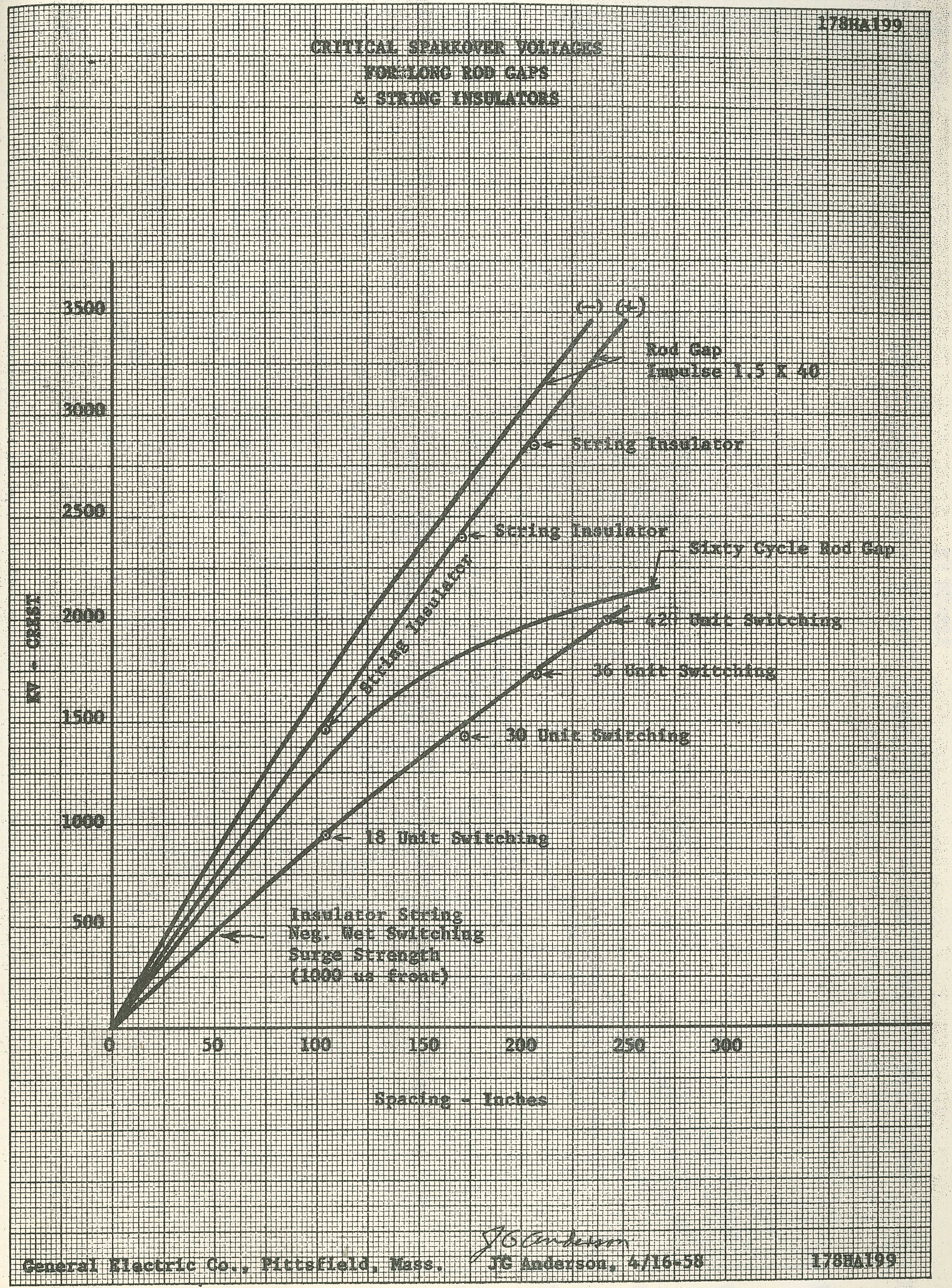
The tower clearances as specified are for equal probability of flashover over the insulator and through the air gap when the insulator is swung in toward the tower at an angle of 30 degrees during bad weather. If, for mechanical reasons, it is preferable for the insulator to arc over rather than to have horizontal flashover to the tower steel (similar to AG&E practice), additional distances must be used to satisfy this requirement.

STATION INSULATION

The calculation of the minimum station insulation is given in Table 2. These calculations are based on the probable performance of the new GE 3-K arrester on 460 KV and 650 KV systems, and on the use of a Form H station-type arrester on the 115 KV circuits. All station insulation is anchored on the selection of the transformer BIL first, and on the assumption of the use of 75% arresters at 460 KV and 650 KV, and an 80% arrester on the 115 KV low side. No arresters are to be used between the regulator and auto-transformer of Fig. 1.

The station insulation to ground is chosen higher than the transformer insulation according to standard procedures. Phase-to-phase spacings are set 1.5 times the phase to ground spacings, but have not been checked in terms of short circuit forces because the phase supports have not yet been selected by the substation designer. It must be recognized that these are minimum values, and since station bus insulation is relatively cheap, the use of higher values may be possible without greatly increased cost or because of radio noise considerations. For example, Western Massachusetts Electric Company has suggested the following spacings for the 115 KV substation circuit

Coordinating Gap: 34.5"
Strike to Ground: 44"
Phase-to-Phase Spacing: 66"


178HA199
CRITICAL SPARKOVER VOLTAGES
FOR LONG ROD GAPS
& STRING INSULATORS
KV - CREST
3500
3000
2500
2000
1500
1000
500
0
50
100
150
200
250
300
Spacing - Inches
(-)
(+)
Rod Gap
Impulse 1.5 X 40
String Insulator
String Insulator
String Insulator
Sixty Cycle Rod Gap
42 Unit Switching
36 Unit Switching
30 Unit Switching
18 Unit Switching
Insulator String
Neg. Wet Switching
Surge Strength
(1000 us front)
General Electric Co., Pittsfield, Mass.
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178HA199

Fig. 2

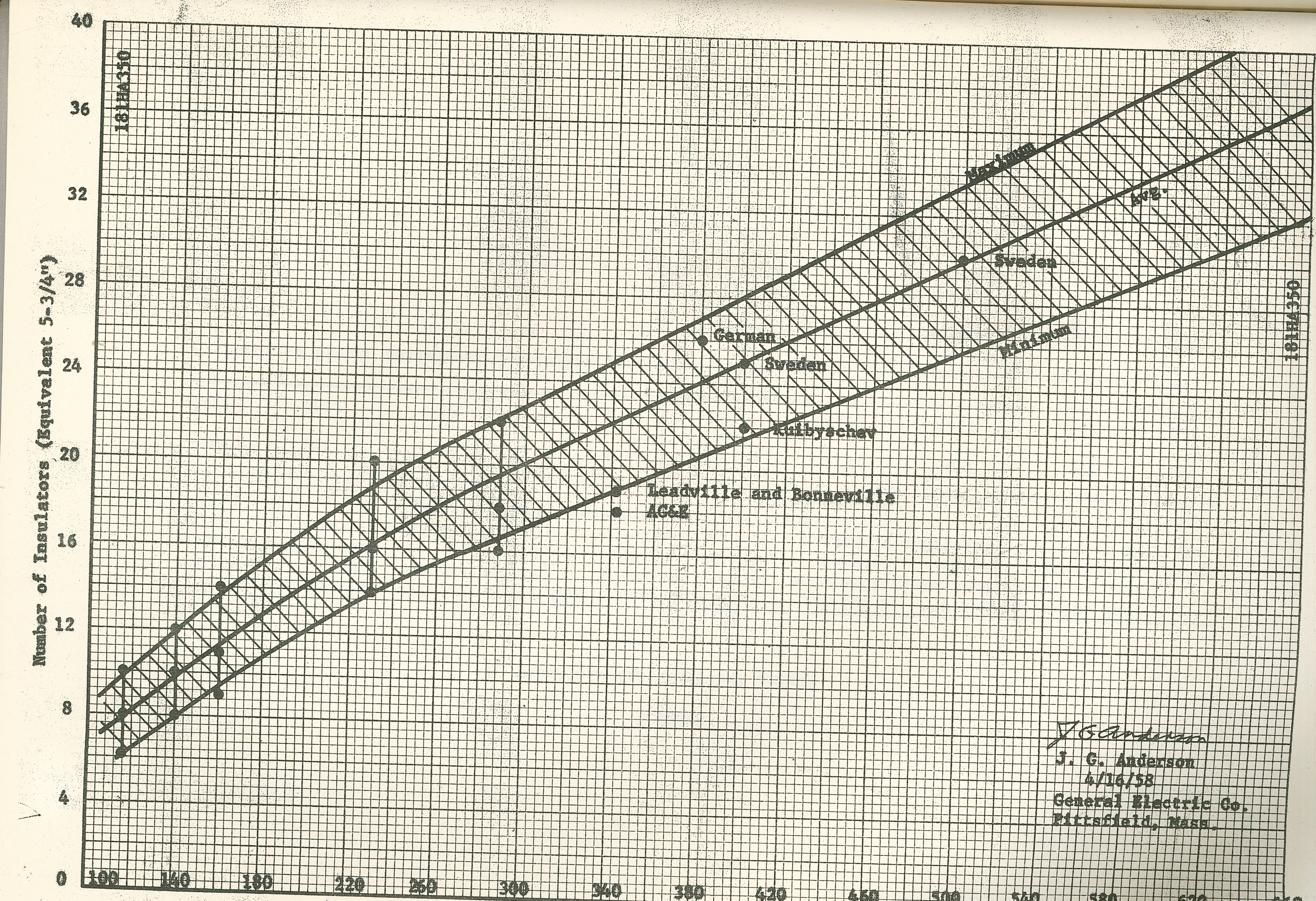

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Fig. 3

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TABLE I

String Insulator Calculations*

System KV	Peak unfaulted line to ground voltage with 5% over-excitation, KV	X 2.8 Switching Surge Magnitude	X 1.1 for difference between withstand and critical flashover	Resulting number of 5-3/4" units from Fig. 2	Additional Units Added for Breakage	Total Number of 5-3/4" Units	Total** Length of Insulator String	Estimated RMS Wet Withstand Strength KV	Line BIL KV
460	394	1105	1215	24	1	25	144"	855	1900
650	557.	1560	1717	35	1	36	207"	1150	2550

*Strengths of clean insulators. In contaminated regions, additional insulation should be added.

**Total length of insulator, excluding hardware.

TABLE 2

Calculation of Minimum Transformer and Station Insulation

System KV	Arrester Rating RMS KV	Required NEMA Minimum Arrester Spark-over Crest KV	60 Cyc Ar-rester Crest Spark-over KV	Arrester KV @ 20 KA Arrester Current	X 1.15 Safety Factor	Plus Ar-rester Lead Drop of Following KV	Total Ar-rester KV	Selected Trans. & Circuit Breaker BIL, KV	Selected Station BIL to Ground KV	** Equiva-lent Rod Gap Spacing Inches	** Phase-to Phase Strike Distance Inches	** Air Dis-connect Gap Spacing Inches
650	513	1090	1340	1550	1785	100	1885	1925	2175	182	272	200
460	363	768	937	1080	1242	75	1317	1425	1550	131	196	144
115	97	203	260	378	435	15	450	450	550	41	62	48
750*	563	1195	1470	1700	1955	100	2055	1925	2175	182	272	200

* For 750 KV, the above arrester values are only rough estimates. Note that the arrester drop is higher than the transformer insulation. The transformer insulation BIL has already been set at 1925 KV and cannot be changed, and the station insulation is coordinated with this value. Hence, the best choice is probably to use the 513 KV lightning arrester, recognizing that it is being operated with a reduced margin of safety at 750 KV.

** Gap spacings are based on the withstand BIL desired, assuming an additional 10% for atmospheric variations and 10% for difference between withstand and critical flashover.

TABLE 3

Tower Clearances & Phase-to-Phase Spacings

System KV	Peak unfaulted line to ground voltage with 5% over-excitation, KV	X 2.8 Switching Surge Magnitude KV	X 1.21 for critical vs withstand and non-standard conditions	Equivalent Gap Distance Inches	Gap Distance for 30 Swing Angle Inches	* Adding Additional Distance Requirements (see below) Inches	** Minimum Phase-to-Phase Spacing Inches	*** Phase-to-Phase Spacing Inches
460	394	1105	1340	145	218	242	290	496
650	557	1560	1885	225	329	353	372	730

* Adding one foot for hardware and one foot for hot line maintenance.

** These are merely rough estimates based on portal type towers with no steel between phases. Calculation made by Mr. S. Minneci from a mechanical formula.

*** Estimated for a corset-type tower with steel between phases.